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证　　　明

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发明创造名称：　微位移变截面均匀细雾化复合式喷油器

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权利要求书 1

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【权利要求1】 7

一种微位移变截面均匀细雾化复合式喷油器，属于内燃机燃油系统的喷油装置，它是由针阀和针阀体组成的一副高精密偶件；其特征在于：其喷油孔截面由针阀和针阀体形成的细环形截面及针阀体出口内锥面上多个小半圆孔或沟槽组成，可形成伞状-多孔油束复合式喷雾，既达到均匀细雾化，又保证了贯穿距。 8

【权利要求2】 9

根据权利要求1所述的一种微位移变截面均匀细雾化复合式喷油器；其特征是，针阀升程为微位移，范围为50～200μm，针阀出口处轴针直径为1.0～3.5mm，喷油束中心延伸线与喷油嘴中心线夹角为50～80度。 10

【权利要求3】 11

根据权利要求1所述的一种微位移变截面均匀细雾化复合式喷油器；其特征是，在针阀体端部与针阀头配合处开有内切锥面，内切锥面上开有多个半圆形油孔或沟槽，针阀头上边缘在整个针阀升程中低于或浸入针阀体前端面，整个针阀头在整个针阀升程中可部分或全部浸入针阀体前端面，当针阀升起时，燃油从针阀头上边缘和内切锥面间喷出，针阀头上边缘和内切锥面共同对油束起导向作用。 12

【权利要求4】 13

根据权利要求1所述的一种微位移变截面均匀细雾化复合式喷油器；其特征是，由针阀和针阀体间形成的喷油通道为’拉法尔’喷管形，喷油通道各转角处有光滑连接，由于针阀升程为微位移，针阀全升程时燃油通道最小截面为50～150μm；取决于针阀和针阀体间的相对运动，燃油喷射初期密封面处为最小间隙截面，燃油喷射中期(针阀升程最大时)针阀出口处为最小间隙截面，燃油喷射后期密封面处为最小间隙截面，最小截面间隙在整个燃油喷射期不大于150μm，从而保证了燃油在整个燃油喷射期得到均匀雾化。 14

【权利要求5】 15

根据权利要求1所述的一种微位移变截面均匀细雾化复合式喷油器；其特征是，在针阀 16

体端部与针阀头配合处内切锥面轴向深度为0.15～1.55mm，内切锥面夹角在120～160度之间。

【权利要求6】 17

根据权利要求1所述的一种微位移变截面均匀细雾化复合式喷油器；其特征是喷油器针阀体顶部内锥面开有5～16个直径为50～250μm的半圆形油孔，所开油孔亦可是最大开口尺度为50～250μm的三角形、梯形或其他多边形或弧形的小沟槽。 18

【权利要求7】 19

根据权利要求1所述的一种微位移变截面均匀细雾化复合式喷油器；其特征是，在发动机小负荷时，燃油主要从针阀和针阀体出口处形成的环形截面喷出，在发动机大负荷时，燃油同时从针阀和针阀体形成的环形截面及阀体出口内锥面上多个半圆孔或沟槽喷出，且燃油从针阀体出口内锥面上多个半圆孔或沟槽喷出的量随负荷而增多，从而保证燃油在整个发动机负荷内得到均匀细雾化和足够的贯穿距。 20

【权利要求8】 21

根据权利要求1所述的一种微位移变截面均匀细雾化复合式喷油器，可用于直喷式柴油机，直喷式汽油机，或其他直喷式代用燃料内燃机。 22

【权利要求9】 23

根据权利要求1所述的一种微位移变截面均匀细雾化复合式喷油器；可用于其他对用量、定时、雾化有特殊要求的喷雾，如用于制造微细粉末，化学汽相淀积。 24

说明书 1

微位移变截面均匀细雾化复合式喷油器 2

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技术领域 4

本发明属内燃机燃油系统的喷油装置，更具体地说，本发明涉及一种微位移均匀雾化的 5
复合式喷油器。

背景技术 6

传统的直喷式柴油机燃烧过程同时包括预混合燃烧和扩散燃烧，并以扩散燃烧为主。近 7
百年来，人们研制成功不同的柴油机燃烧系统。就其特点，多数系统是扩散燃烧。由于扩散燃烧混合气的形成极不均匀，因而具有难以克服的排烟和NOX间的矛盾。近年来，随着电控和高压喷射等技术的发展，柴油机的燃烧和排放得以很大的改善，但扩散燃烧的本质问题仍有待解决。随着各国排放法规的日益严格，柴油机的燃烧和排放面临着更大的挑战。

近年来，均质压燃燃烧(HCCI)在国际上受到重视。HCCI 的目标是在着火前形成均质混 8
合气，原则上消除扩散燃烧，故有同时消除碳烟和降低NOX的潜力。但目前HCCI面临的主要问题是难以控制着火始点和燃烧速率，只能在部分工况下正常运行，因而实际运用面临着很大的挑战。我国学者提出了热预混合燃烧的思想，并用伞喷油嘴来促进均匀混合(中国专利86104093，90106022)。伞喷燃烧在低负荷下性能较好，但高负荷下易产生黑烟，因伞喷供油速率快，喷雾贯穿距较小，难以控制高负荷下油气的时空分布。

为了促进均匀混合气的形成，国际上通常采用多个细油孔喷油器和高压喷射， 但油孔 9
过细流动阻逆增大且易堵塞， 喷射压力过高则油泵耗能增大，高压喷射系统的成本亦随之提高。一种具有良好工艺性和可靠性的均匀雾化的喷油器无疑具有重要的环保和节能意义。

发明内容 10

本发明给出了一种微位移变截面均匀雾化的复合式喷油器，解决目前预混合直喷式内燃 11
机燃烧面临的难以解决的均质混合的主要问题，既达到均匀细雾化，又保证了贯穿距，同时降低排放中的碳烟，NOX和HC 产物。本发明可用于直喷式柴油机，亦可用于直喷式汽油机，或其他代用燃料内燃机。

本发明是通过以下技术方案来实现的。 12

本发明所述的一种微位移变截面均匀细雾化复合式喷油器，属于内燃机燃油系统的喷油 13
装置，它是由针阀和针阀体组成的一副高精密偶件；其喷油孔截面由针阀和针阀体形成的细环形截面及针阀体出口内锥面上多个小半圆孔或沟槽组成，可形成伞状-多孔油束复合式喷

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雾，既达到均匀细雾化，又保证了贯穿距。

本发明所述的一种微位移变截面均匀细雾化复合式喷油器：所述的针阀升程为微位移， 14
范围为50～200μm，针阀出口处轴针直径为1.0～3.5mm，喷油束中心延伸线与喷油嘴中心线夹角为50～80度。

本发明所述的一种微位移变截面均匀细雾化复合式喷油器：在针阀体端部与针阀头配合 15
处开有内切锥面，内切锥面上开有多个半圆形油孔或沟槽，针阀头上边缘在整个针阀升程中低于或浸入针阀体前端面，整个针阀头在整个针阀升程中可部分或全部浸入针阀体前端面，当针阀升起时，燃油从针阀头上边缘和内切锥面间喷出，针阀头上边缘和内切锥面共同对油束起导向作用。

本发明所述的一种微位移变截面均匀细雾化复合式喷油器：由针阀和针阀体间形成的喷 16
油通道为′拉法尔′喷管形，喷油通道各转角处有光滑连接，由于针阀升程为微位移，针阀全升程时燃油通道最小截面为50～150μm；取决于针阀和针阀体间的相对运动，燃油喷射初期密封面处为最小间隙截面，燃油喷射中期(针阀升程最大时)针阀出口处为最小间隙截面，燃油喷射后期密封面处为最小间隙截面，最小截面间隙在整个燃油喷射期不大于150μm，从而保证了燃油在整个燃油喷射期得到均匀雾化。

本发明所述的一种微位移变截面均匀细雾化复合式喷油器：所述的在针阀体端部与针阀 17
头配合处内切锥面轴向深度为0.15～1.55mm，内切锥面夹角在120～160度之间。

本发明所述的一种微位移变截面均匀细雾化复合式喷油器：所述的喷油器针阀体顶部内 18
锥面开有5～16个直径为50～250μm的半圆形油孔，所开油孔亦可是最大开口尺度为50～250μm的三角形、梯形或其他多边形或弧形的小沟槽。

本发明所述的一种微位移变截面均匀细雾化复合式喷油器：在发动机小负荷时，燃油主 19
要从针阀和针阀体出口处形成的环形截面喷出，在发动机大负荷时，燃油同时从针阀和针阀体形成的环形截面及阀体出口内锥面上多个半圆孔或沟槽喷出，且燃油从针阀体出口内锥面上多个半圆孔或沟槽喷出的量随负荷而增多，从而保证燃油在整个发动机负荷内得到均匀细雾化和足够的贯穿距。

本发明所述的一种微位移变截面均匀细雾化复合式喷油器，可用于直喷式柴油机，直喷 20
式汽油机，或其他直喷式代用燃料内燃机。

本发明所述的一种微位移变截面均匀细雾化复合式喷油器：可用于其他对用量、定时、 21
雾化有特殊要求的喷雾，如用于制造微细粉末，化学汽相淀积。

本发明与现有技术方案相比有如下优点:1) 微位移变截面均匀细雾化复合式喷油器，由 22

于其喷油出口截面具有可变性，最小截面间隙在整个燃油喷射期不大于150μm，能在整个发动机负荷内形成均匀微细喷雾，环状喷雾间隙由于相当于无数个细小多孔相连，同时可保证高的供油速率和短的喷油期，易形成均匀预混合气，能显著地降低碳烟的生成；均匀微细喷雾使压燃式发动机更逼近均质压燃燃烧，从而降低了燃烧温度和NOx；均匀微细喷雾为进一步改善直喷式汽油机燃烧提供了重要条件；2）本发明所述的均匀雾化复合式喷油器，由于其喷油出口截面具有可变性，对油品的质量具有很好的适应性，油孔不易堵塞，具有良好的可靠性；3）本发明所述的微位移变截面均匀细雾化复合式喷油器，由于采用针阀微位移，为采用压电陶瓷等高精度微位移驱动器提供了有利条件，这为满足更严格的排放法规提供了重要条件。

附图说明 23

图1为微位移变截面均匀细雾化复合式喷油器总体示意图； 24

图2为图1中微位移变截面均匀细雾化复合式喷油器油孔端部放大图； 25

图3为图1中复合式喷油器油孔端部仰视图； 26

图4为图1中复合式喷油器喷雾形状示意图； 27

图5为图1中复合式喷油器油孔端部的针阀体立体图。 28

图中： 1 － 针阀；　2 － 针阀密封面；　3 － 针阀头部； 29

4 － 复合油孔截面(包括环截面和沟槽)；　5 － 针阀体；　6 － 油孔沟槽； 30

7 － 针阀体端面；　A － 针阀头部上边缘；B － 针阀头部与针阀体前端面交界面； 31

C － 针阀体端面内切锥面；　D － 针阀体端部内孔； 32

具体实施方式 33

对车用柴油机和其它小型柴油机，微位移变截面均匀细雾化复合式喷油器可采用图2方案， 其特征是所述喷油器尺寸为： 34

$d1 = 4 \sim 6$ mm； $d1 - d2 = 0.3 \sim 0.6$ mm； $d3 = 1.0 \sim 2.5$ mm； 35

针阀体油孔直径 － $d3 = 10 \sim 20$ μm； 36

密封处锥面夹角 ＝ 50 ～ 75度； 针阀升程 ＝ 75 ～ 200 μm； 37

针阀体端面内切锥面夹角 ＝ 120 ～ 150 度； 38

针阀体端面内切锥面上的油孔/沟槽数 ＝ 6 ～ 12 个； 39

针阀体端面内切锥面上的油孔直径 ＝ 50 ～ 250 μm； 40

对中型柴油机， $d1 = 5 \sim 6$ mm； $d1 - d2 = 0.4 \sim 0.6$ mm； 41

$d3 = 1.5 \sim 3.0$ mm， 其他参数可采用与以上小型柴油机类似的方案。 42

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对直喷式汽油机， d1 = 5 ～ 6 mm；d1 - d2 = 0.3 ～ 0.5 mm；d3 = 1.5 ～ 2.5 mm，针阀体端面内切锥面夹角 = 120 ～ 145 度；密封处锥面夹角 = 50 ～ 70度；

其他参数可采用与以上小型柴油机类似的方案。

说明书附图

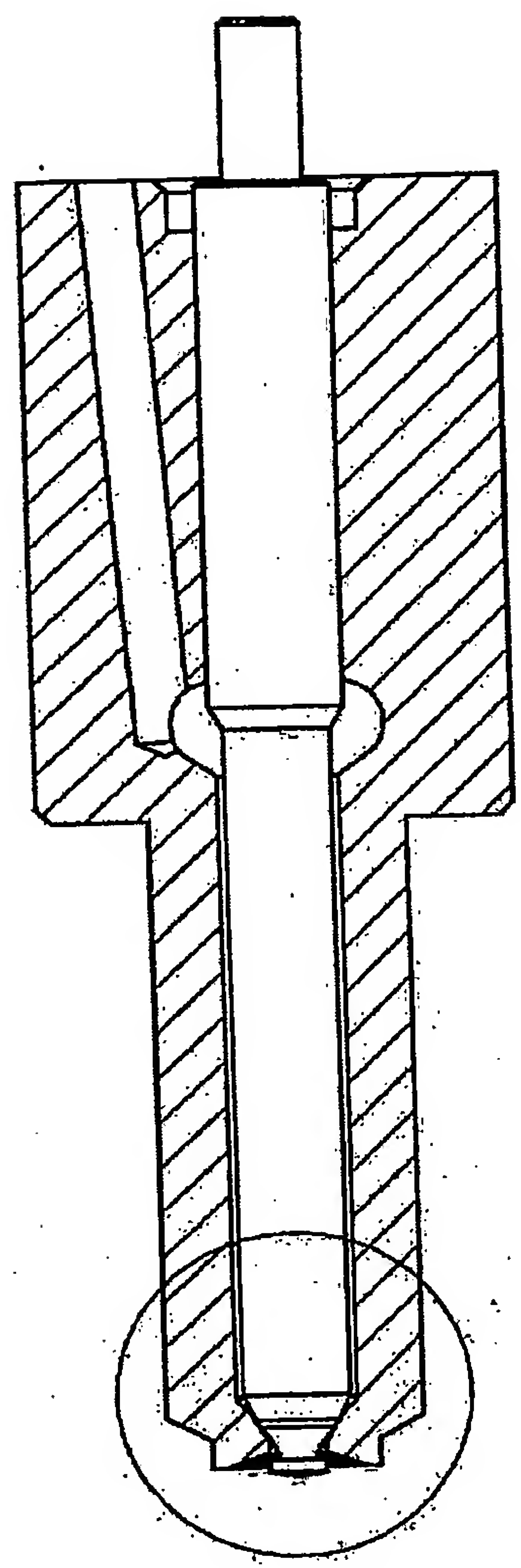

图1

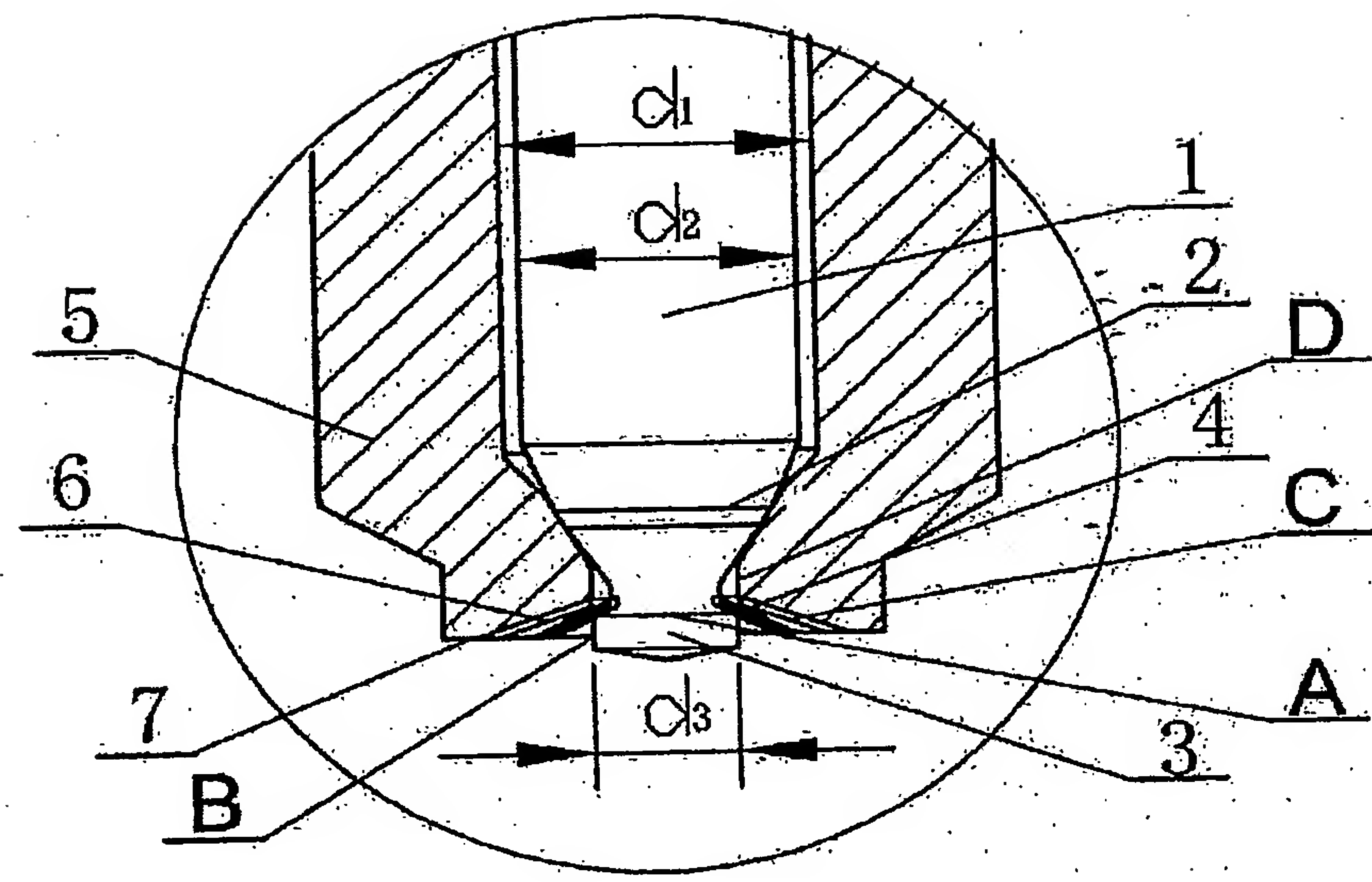

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图2

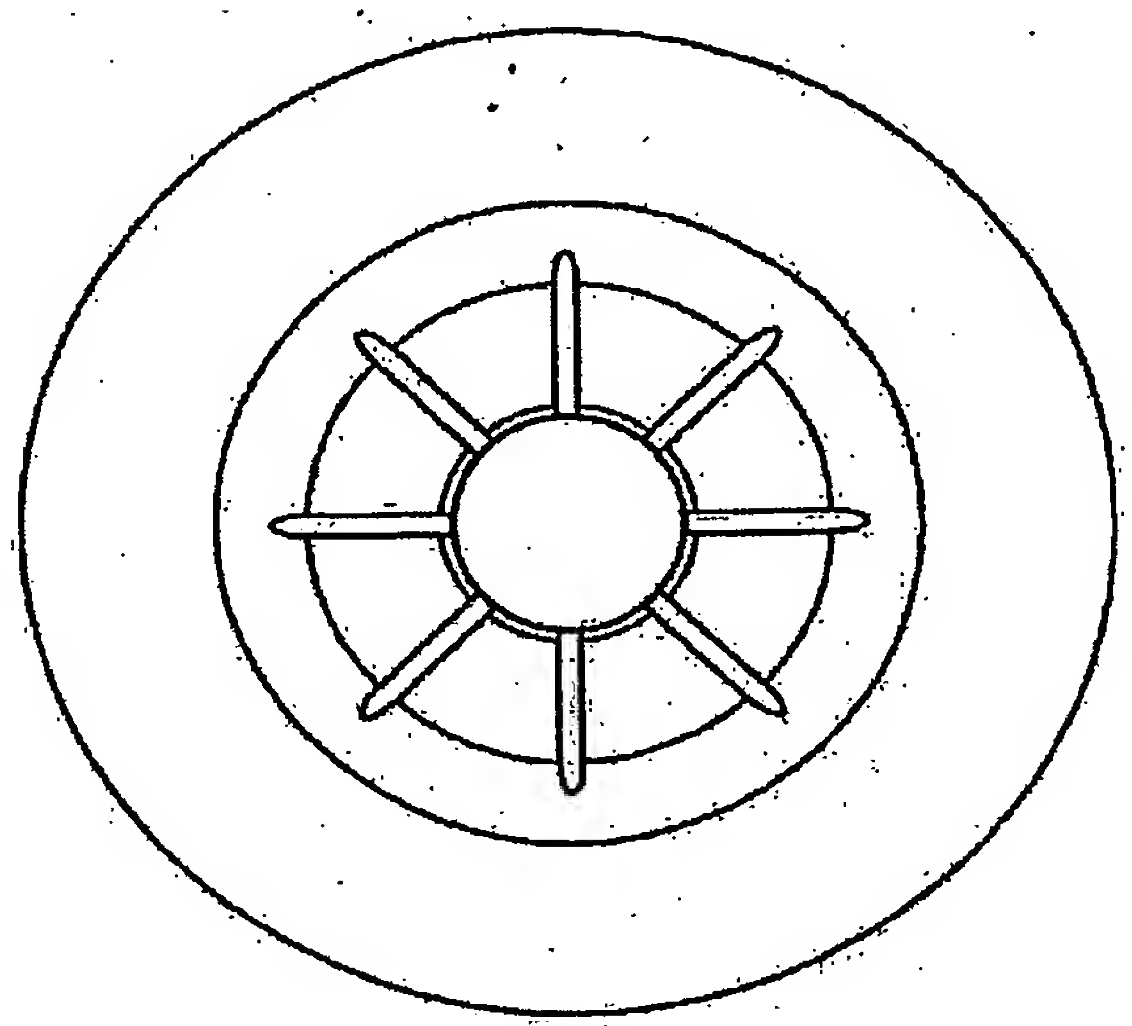

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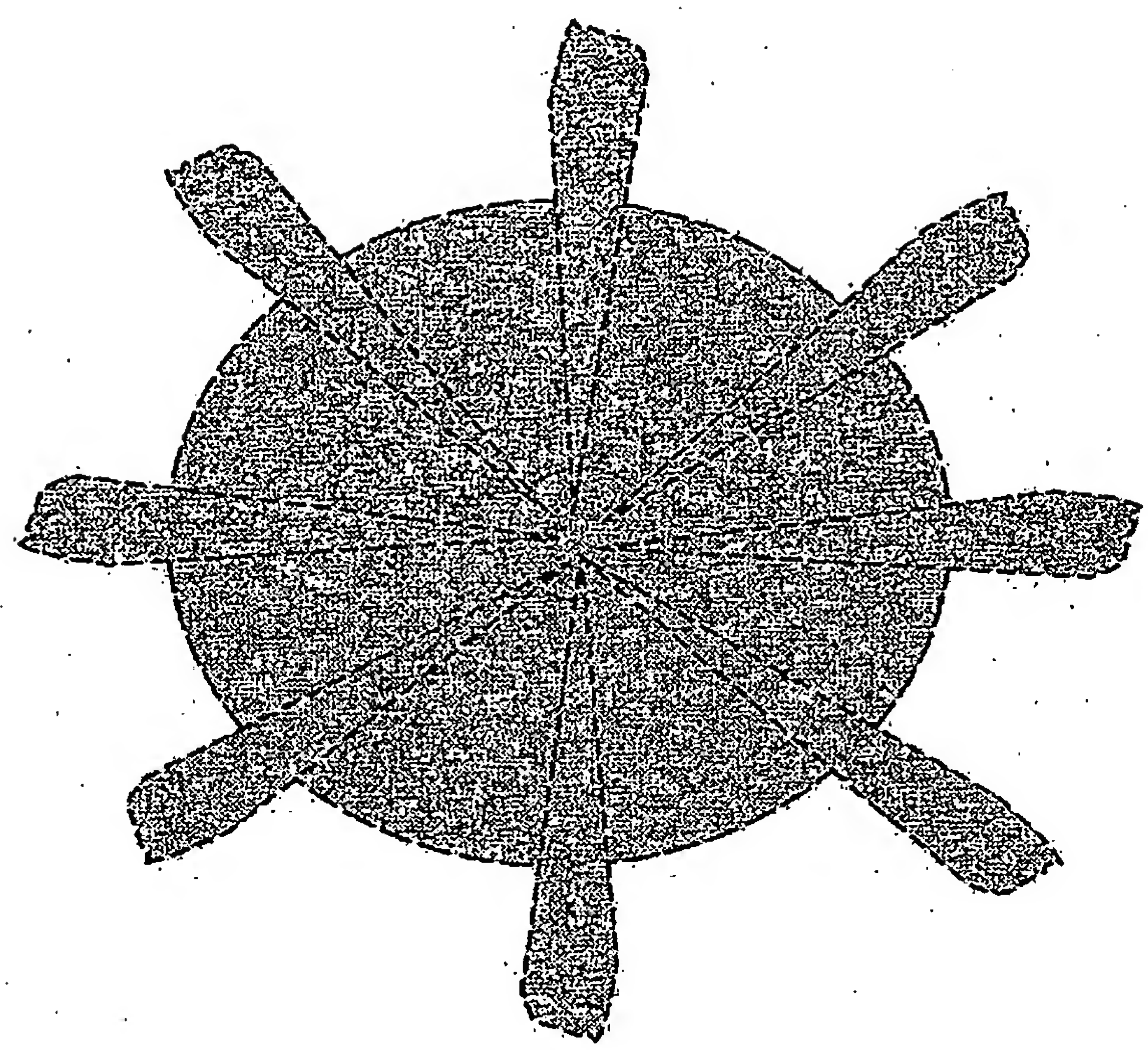
图3



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12

图4

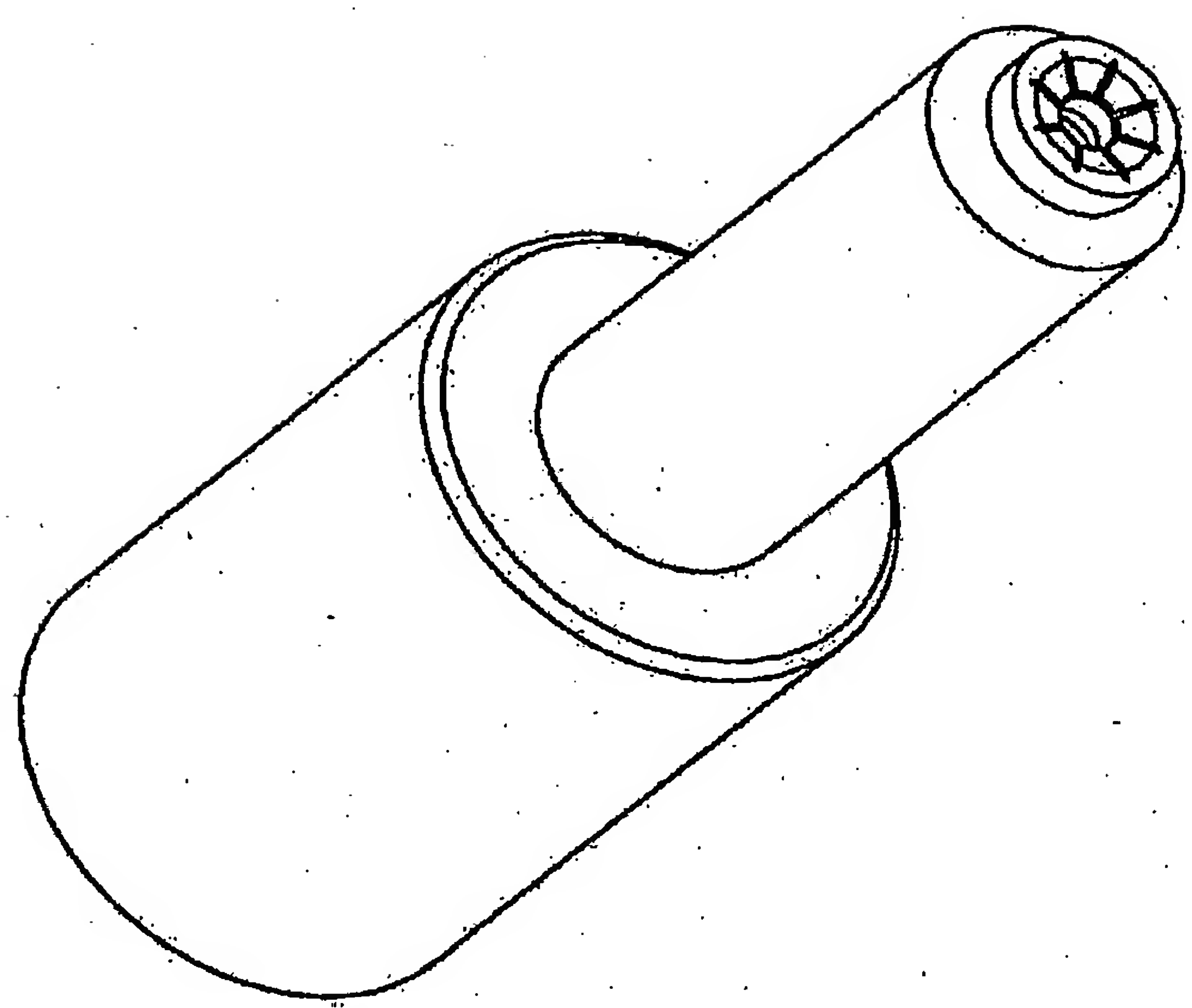

图5

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APPLICATION NUMBER: *60/594,110*
FILING DATE: *March 11, 2005*

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Certifying Officer

TRANSMITTAL

Electronic Version v1.1

Stylesheet Version v1.1.0

Title of Invention	A MIXED-MODE FUEL INJECTOR WITH A MICRO VARIABLE CIRCULAR ORIFICE

Application Number :

Date :

First Named Applicant: Dr. Deyang Hou

Confirmation Number:

Attorney Docket Number:

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Submitted By:	Elec. Sign.	Sign. Capacity
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Documents being submitted:	Files
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	us-fee-sheet.xsl
	us-fee-sheet.dtd
us-declaration	HOU-INJECTOR-usdecl.xml
	us-declaration.dtd
	us-declaration.xsl
us-request	HOU-INJECTOR-usrequ.xml
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	Image1.tif
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Comments	

APPLICATION DATA SHEET

Electronic Version v14

Stylesheet Version v14.1

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Application Information:

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A MIXED-MODE FUEL INJECTOR WITH A MICRO VARIABLE CIRCULAR ORIFICE

DESCRIPTION

BACKGROUND OF THE INVENTION

[Para 1] 1. Field of the Invention – The invention relates to a mixed-mode fuel injector with a micro-variable-circular-orifice (MVCO) and homogeneous atomization, and particularly to a fuel injector for a direct injection internal combustion engine, which may be either a spark-ignition gasoline engine or a compression-ignition diesel engine. The current invention is focused on the nozzle part of the fuel injector. The fuel injector is a high-accuracy couple of components composed with a needle and a nozzle body, which system has a micro-variable-circular-orifice (MVCO) composed of a variable circular aperture between a needle and a nozzle body and multiple-micro-channels on the inner conical surface close to the tip of the nozzle body, therefore it is capable of generating variable mixed-mode sprays composed of conical and multiple-jet shapes, which form a major homogeneous conical spray at low engine load, and mixed-mode sprays composed of conical and multiple-jet at high loads. The mixed-mode sprays ensure homogeneous fine atomization and sufficient penetration simultaneously.

[Para 2] 2. Description of the Related Art – The combustion process in a conventional direct injection Diesel engine is characterized by diffusion combustion with a multiple-hole fuel injector. Due to its intrinsic non-homogeneous characteristics of fuel-air mixture formation, it is contradictory to simultaneously reduce soot and NOx formation in a diesel engine. Over the years, significant progress has been made for Diesel engine combustion (United States Patents No. 4,779,587, 6,230,683), but further reducing emissions from

Diesel engines to address to upcoming emission legislations still remains a challenge. Progress has been made in recent years for the research of Homogeneous-Charge Compression-Ignition (HCCI) combustion engines. However, it is still a challenge to find a practical approach to control the ignition timing, the duration of combustion, the rate of combustion for HCCI engine for various load conditions. Current control strategies, such as US Patent No. 6,230,683, are effective but very complex and will increase the cost for applications. It seems more a viable solution to operate engine in a mixed-mode, or in HCCI mode or close to HCCI mode at low to medium load, and operate engine in conventional spray combustion mode at high loads for the near future. It would be desirable to design a fuel injector which can accommodate such mixed-mode combustion, at least provide most features needed by optimal engine combustion..

[Para 3] To improve combustion at the full load range, fine atomization with accurate control of doses and timing are needed. A well-known current art for improving atomization is to increase the number of holes of nozzles and decrease the diameter of nozzle holes, and use piezo actuators and high common rail pressure (United States Patents 6,726,121, 6,557,779), such as BOSCH's piezo-injector with coaxial-vario-nozzle (Roger Busch, Advanced Diesel Common Rail Injection System for Future Emission Legislation, DEER 2004). Such an approach, while effective for improving atomization and combustion, it does, at the same time, mandate a very complex structure and a much higher rail pressure, thus increase the power needed for fuel pump and manufacture cost of fuel systems, and increase the potential risks of fuel leaking. Our objective is to design a fuel injector with homogeneous fine atomization with sufficient penetration for full load ranges without the strict requirement for high rail pressure.

SUMMARY OF THE INVENTION

[Para 4] This invention provides a novel design of a fuel injector, more specifically a novel nozzle injection structure with a micro variable circular aperture and micro-channels to reduce pressure loss in the injector channel and compose a homogeneous initial fuel distribution. The mixed-mode fuel injector can generate a homogeneous fine atomization with sufficient penetration without relying on excessive high rail pressure. The fuel injector is a high-accuracy couple of components with a needle and a nozzle body, which system has a micro-variable-circular-orifice (MVCO) composed of a variable circular aperture between needle and nozzle body and multiple micro-channels on the inner conical surface closing to the nozzle body tip, therefore it is capable of generating variable mixed-mode sprays of conical and multiple-jet shapes, with a major circularly homogeneous conical spray at low to medium engine loads, and mixed-mode sprays composed of a conical spray and multiple-jets at high loads. The mixed-mode-spray ensures homogeneous atomization and sufficient penetration simultaneously.

[Para 5] This invention has following major merits: (1) Due to the fact that the micro-variable-circular-orifice (MVCO) is equivalent to a connection of infinite number of micro-holes, thus this fuel injector can form a variable micro aperture for fine atomization and ensure high fuel injection rate simultaneously. It enables using a micro-needle-lift needle, which is desired for working with a piezo actuator or hydraulic pressure amplifier to accurately control the fuel injection dose and atomization quality and give a much shorter response time. (2) The special design provides a homogeneous fine atomization at low to medium loads, thus it is favorable for HCCI combustion mode, and provide fine atomization and sufficient penetration at high engine loads, thus it ensures engine power output. The varying micro-variable-circular-orifice (MVCO) feature can provide different size of the injection area, thus can provide different fuel atomization rate and SMD (Sauter Mean

Diameter) based on the need for optimal combustion for different load and speed conditions. (3) Since the micro-variable-circular-orifice (MVCO) keeps varying during the fuel injection process, the needle has a self-cleaning effect, that is, it is more robust for eliminating clogging. This feature has more merits than traditional multi-hole nozzle, which is easy to get clogged and have heavy injection pressure loss when the injection hole is too small. This fuel injector provides a key device for meeting the current and future engine emission regulations. (4) The special design of the flow channel in the injector reduces pressure loss comparing with a conventional multi-hole nozzle. The MVCO can produce fine atomization with much smaller SMD (around 10 μm) with rail pressure under 100MPa. (5) Given many desirable features for combustion, this fuel injector also has a relatively simple structure, thus can save the manufacturing cost and provide a cost effective solution for improving engine combustion.

BRIEF DESCRIPTION OF THE DRAWINGS

[Para 6] FIG. 1 is a fragmentary sectional view of a first exemplary embodiment of an injector of the invention;

[Para 7] FIG. 2 is an amplified fragmentary sectional view of FIG. 1 for the micro-variable-circular-orifice (MVCO);

[Para 8] FIG. 3 is a bottom-up view of FIG. 1 for the micro-variable-circular-orifice (MVCO);

[Para 9] FIG. 4 is an illustration of the mixed-mode conical-multiple-jet spray generated by the embodiment of the fuel injector illustrated in FIG. 1;

[Para 10] FIG. 5 is a fragmentary three-dimensional view of the fuel injector in FIG. 1;

[Para 11] In all the figures, 1 – needle; 2 – needle sealing surface; 3 – needle head; 4 – micro-variable-circular-orifice (MVCO) (including a circular aperture and micro channels); 5 – nozzle body; 6 – micro fuel channels; 7 – tip surface of the nozzle body; A – up-rim of the needle head; B – the intersection of the needle head and tip surface of nozzle body; C – conical surface at the tip surface of the nozzle body; D – inner hole of the tip of the nozzle body.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[Para 12] The fuel injector is a high-accuracy couple of components with a needle (1 in FIG. 2), which has a opening and a biased closing position, which is movable back and forth and received in a nozzle body (5 in FIG. 2) axially counter to the prestressing force of a nozzle spring that is received in a nozzle spring chamber, and which system has micro-variable-circular-orifice (MVCO) (4 in FIG. 2) composed of a variable circular aperture between needle (1) and nozzle body (5) and multiple micro-channels (6) on the inner conical surface (C) closing to the nozzle body tip (FIG.1, FIG.2, FIG. 3), therefore it is capable of generating variable mixed-mode sprays of conical and multiple-jet shapes (FIG. 4), with a major circularly homogeneous conical spray at low to medium loads, and variable mixed-mode fuel sprays at high loads to ensure homogeneous atomization and sufficient penetration simultaneously.

[Para 13] The said mixed-mode fuel injector, wherein the needle lift is micro-motion with a range of 40-200μm, the included angle of the sealing surface (2) at the nozzle body is between 50-70 degree, the needle head diameter (d_3) is between 0.8-3.5mm, the angle between the centerline of the nozzle body and the inner conical surface (C) at the nozzle body tip is in the range of 40-75 degree.

[Para 14] The said mixed-mode fuel injector (FIG. 2), wherein close to the tip surface (7) of nozzle body there is a conical surface (C), which is a smooth surface, the conical surface can be a single conical surface, or can be an integrated conical surface composed with two or more conical surfaces with different conical angles, or a diverging curve surface, the upper rim (A) of the needle head (3) is merged in the tip surface (7) of the nozzle body during the needle lifting, the needle head (3) can be partially or wholly merged in the tip surface (7) of the nozzle body during the needle lifting, when the needle is lifted, fuel is injected through the aperture (4) between the needle head and conical surface (C) of the nozzle body.

[Para 15] The said mixed-mode fuel injector (FIG. 2), wherein close to the tip surface (7) of nozzle body there is a conical surface (C), the conical surface can be a single conical surface, or can be an integrated conical surface composed with two or more conical surfaces with different conical angles, or a diverging curve surface, the conical surface close to the needle is a surface with multiple micro-channels (6) with the shape of semi-circle, triangle, trapezoid or other polygons, or arcs, or with helical micro-channels, the upper rim (A) of the needle head (3) is merged in the tip surface (7) of the nozzle body (5) during the needle lifting, the needle head can be partially or wholly merged in the tip surface (7) of the nozzle body during the needle lifting, when the needle is lifted, fuel is injected through the variable aperture between the needle head and conical surface (C) of the nozzle body, fuel is also injected through the multiple micro-channels (6), the upper surface of the needle head (3) and the conical surface (C) serve as guiding surfaces for sprays.

[Para 16] The said mixed-mode fuel injector, wherein the fuel channel between the needle head (3) and conical surface (C) of the nozzle body is of converging-diverging nozzle shape, there are smooth connections along the corners of the fuel channel, due to micro-needle-lift of the needle, the lifted minimum dimension of the aperture of the

channel is in the range of 30-120μm, the minimum aperture is at the sealing surface (2) during the early stage of fuel injection, the minimum aperture is at the needle exit injection-cross-section (4) or at the sealing surface (2), depending on a specific design, during the middle stage of fuel injection, and the minimum aperture is at the sealing surface again during the late stage of fuel injection, during all fuel injection stages, the minimum aperture is less than 120 μm, thus ensures fine atomization during all fuel injection stages.

[Para 17] The said mixed-mode fuel injector, wherein the depth of conical surface (C) close to the nozzle exit is between 0.15-3mm, the conical angle of conical surface (C) is between 80-150 degree.

[Para 18] The said mixed-mode fuel injector (FIG. 1, FIG.2), wherein there are 5-18 micro-channels (6) with the cross-section shape of either semi-holes with the diameters in the range of 50-300μm, or other shapes as described above with the maximum dimension between 50-400μm (i.e., the geometric cross section of such a channel can fit in a circle with a diameter of 50-400μm), the sizes of these micro-channels can be the same or varying depending on specific needs of atomization, these micro-channels can be homogeneously or non-homogeneously distributed on the conical surface(C).

[Para 19] The said mixed-mode fuel injector, wherein at low to medium engine loads, fuel is mainly injected from the variable circular aperture between the needle head and nozzle body, thus mainly forms a conical shape spray, while at high loads, fuel is injected through both the variable circular aperture between the needle head and nozzle body and the micro-channels (6) on the conical surface(C), fuel forms mixed-mode conical-multiple-jet shape sprays (FIG. 4), thus ensures both fine atomization and sufficient penetration.

[Para 20] The said mixed-mode fuel injector, wherein the angle between the centerline of the conical surface (C) and the centerline of the nozzle body (5) is between 0-15 degree,

depending on the angle between the centerline of the fuel injector and the centerline of the piston in the engine cylinder.

[Para 21] The said mixed-mode fuel injector, is intended but not limited to direct injection diesel engines, direct injection gasoline engines, or other direct injection alternative fuel engines, it is intended for mechanical, electro-mechanical, piezo fuel injectors, or fuel injectors with hydraulic pressure amplifiers.

[Para 22] For small direct injection diesel engines, the major dimensions for the mixed-mode fuel injector are: $d_1 = 3.0 - 5$ mm; $d_1 - d_2 = 0.3 - 0.8$ mm; $d_3 = 0.8 - 2.5$ mm; the diameter of nozzle body hole - $d_3 = 10 - 18$ μm; the included angle at sealing surface at nozzle body = 50 - 75degree; the needle-lift range = 30 - 200 μm; the cone angle of the conical surface at the tip of nozzle body = 110 - 150 degree; the number of micro channels on the conical surface (C) = 6 - 18; the maximum dimension of the micro channels (6) = 50 - 300 μm.

[Para 23] For medium size direct injection diesel engines, the major dimensions for the mixed-mode fuel injectors are: $d_1 = 4 - 6$ mm; $d_1 - d_2 = 0.4 - 0.8$ mm; $d_3 = 1.0 - 3.0$ mm;

[Para 24] The cone angle of the conical surface (C) = 130 - 150 degree; the maximum dimension of the micro channels (6) = 50 - 400 μm; other parameters are similar to small diesel engines. The rail pressure for the said mixed-mode fuel injector is about 800 - 1200 bar, while higher is better, it is not required for fine atomization. The open pressure is above 240 bar.

[Para 25] For direct injection gasoline engines, the major dimensions for the mixed-mode fuel injectors are: $d_1 = 3.5 - 5.5$ mm; $d_1 - d_2 = 0.4 - 0.8$ mm; $d_3 = 1.0 - 2.5$ mm, the cone angle of the conical surface (C) = 70 - 130 degree; the included angle at sealing surface at nozzle body = 50 - 70 degree. The open pressure of injector for gasoline engine is about 50-100 bar.

[Para 26] The said mixed-mode fuel injector, is intended for but not limited to internal combustion engines. The outer surface of the nozzle body can be of cylindrical, conical, or converging-diverging shape.

[Para 27] The people who are familiar with the art of the field will find that it's easy to make minor changes to the nozzle structure following the same invention, such as adding micro-channels or adding spirals on the needle head or on the conical surface(C) of the nozzle body, these minor changes are within the scope of this invention.

What is claimed is:

[Claim 1] 1. A mixed-mode fuel injector with a micro-variable-circular-orifice (MVCO) and homogeneous atomization, which belongs to fuel injection devices of internal combustion engine, the fuel injector is a high-accuracy couple of components with a needle, which has an opening and a biased closing position, which is movable back and forth and received in a nozzle body axially counters to the pre-stressing force of a nozzle spring that is received in a nozzle spring chamber, which system has a micro-variable-circular-orifice (MVCO) composed of a circular aperture between needle and nozzle body and multiple micro-channels on the inner conical surface closing to the nozzle body tip, therefore it is capable of generating variable mixed-mode sprays of conical and conical-multiple-jet shapes, with a major circularly homogeneous conical spray at low to medium loads, and variable mixed-mode conical-multi-jet sprays at high loads to ensure homogeneous atomization and sufficient penetration simultaneously.

[Claim 2] 2. The mixed-mode fuel injector of claim 1, wherein the needle lift is micro-motion with a range of 40-200μm, the included angle of the sealing surface at the nozzle body is between 50-70 degree, the needle head diameter is between 0.8-3.5mm, the angle between the centerline of the nozzle body and the inner conical surface at the nozzle body tip is in the range of 40-75 degree.

[Claim 3] 3. The mixed-mode fuel injector of claim 1, wherein close to the tip surface of nozzle body there is a conical surface, which is a smooth surface, the

conical surface can be a single conical surface, or can be an integrated conical surface composed with two or more conical surfaces with different conical angles, or a diverging curve surface, the upper rim of the head of the needle is merged in the tip surface of the nozzle body during the needle lifting, the needle head can be partially or wholly merged in the tip surface of the nozzle body during the needle lifting, when the needle is lifted, fuel is injected through the variable aperture between the needle head and conical surface of the nozzle body.

[Claim 4] 4. The mixed-mode fuel injector of claim 1, wherein close to the tip surface of nozzle body there is a conical surface, the conical surface can be a single conical surface, or can be an integrated conical surface with two or more conical surfaces with different conical angles connected together, or a diverging curve surface, the conical surface close to the needle has multiple micro-channels with the cross section shape of semi-circle, triangle, trapezoid or other polygons, or arcs, or with helical micro-channels, the upper rim of the head of the needle is merged in the tip surface of the nozzle body during the needle lifting, the needle head can be partially or wholly merged in the tip surface of the nozzle body during the needle lifting, when the needle is lifted, fuel is injected through the variable aperture between the needle head and conical surface of the nozzle body, fuel is also injected through the multiple micro-channels, the upper surface of the needle head and the conical surface(s) serve as guiding surfaces for sprays.

[Claim 5] 5. The mixed-mode fuel injector of claim 1, claim 3, or claim 4, wherein the fuel channel between the needle head and conical surface of the nozzle body is of converging-diverging nozzle shape, there are smooth connections along the corners of the fuel channel, due to micro-needle-lift of the needle, the lifted minimum aperture of the channel is in the range of 30-120μm, the minimum aperture is at the sealing surface during the early stage of fuel injection, the minimum aperture is at the micro-variable-circular-orifice (MVCO) or at the sealing surface, depending on a specific design, during the middle stage of fuel injection, and the minimum aperture is at the sealing surface again during the late stage of fuel injection, during all fuel injection stages, the minimum aperture is less than 120 μm, thus it ensures fine atomization during all fuel injection stages.

[Claim 6] 6. The mixed-mode fuel injector of claim 1, wherein the depth of conical surface close to the nozzle exit is between 0.15-3mm, the conical angle of the conical surface is in the range of 80-150 degree.

[Claim 7] 7. The mixed-mode fuel injector of claim 1or claim 4, wherein there are 5-18 micro-channels with the cross-section shape of either semi-circles with the diameters in the range of 50-300μm, or other shapes as described in claim 4 with the maximum dimension between 50-400μm, the sizes of these micro-channels can be the same or different depending on specific needs of atomization, these micro-channels can be homogeneously or non-homogeneously distributed on the conical surface.

[Claim 8] 8. The mixed-mode fuel injector of claim 1or claim 4, wherein at low to medium engine loads, fuel is mainly injected from the variable circular aperture between the needle head and nozzle body, thus it mainly forms a conical shape spray, while at high loads, fuel is injected through both the variable circular aperture between the needle head and nozzle body and the micro-channels on the conical surface(C), fuel forms a mixed-mode conical-multiple-jet shape spray, thus it ensures both fine atomization and sufficient penetration.

[Claim 9] 9. The mixed-mode fuel injector of claim 1, claim 3 or claim 4, wherein the angle between the centerline of the conical surface and the centerline of the nozzle body is between 0-15 degree, depending on the angle between the centerline of the fuel injector and the centerline of the piston in the engine cylinder.

[Claim 10] 10. The mixed-mode fuel injector of claim 1, claim 3 or claim 4, is intended for but not limited to direct injection diesel engines, direct injection gasoline engines, or other alternative fuel direct injection engines, it is intended for mechanical, electro-mechanical, piezo fuel injectors, or fuel injectors with hydraulic pressure amplifiers.

[Claim 11] 11. The mixed-mode fuel injector of claim 1, claim 3 or claim 4, wherein the outer surface of the nozzle body can be of cylindrical, conical, or converging-diverging shape.

[Claim 12] 12. The people who are familiar with the art of the field will find that it's easy to make minor changes to the nozzle structure following the same invention, such as adding micro-channels or adding spirals on the needle head or the conical surface(C) of the nozzle body, these minor changes are within the scope of this invention.

ABSTRACT

The invention relates to a mixed-mode fuel injector with micro-variable-circular-orifice (MVCO) and homogeneous atomization, which belongs to fuel injection devices of internal combustion engine. The fuel injector is a high-accuracy couple of components with a needle and a nozzle body, which system has a MVCO composed of a micro-variable-circular aperture between the needle and the nozzle body and multiple-micro-channels on the inner conical surface close to the tip of the nozzle body, it is capable of generating variable mixed-mode sprays of conical and multi-jet shapes, with a major homogeneous conical spray at low to medium loads. The mixed-mode injector ensures homogeneous fine atomization and sufficient penetration simultaneously. The injector with MVCO provides features desired for mixed-mode combustion of HCCI and conventional direct injection engines.

DECLARATION (37 CFR 1.63) FOR UTILITY OR DESIGN APPLICATION USING AN APPLICATION DATA SHEET (37 CFR 1.76)

Electronic Version v11

Stylesheet Version v10

Title of Invention	A MIXED-MODE FUEL INJECTOR WITH A MICRO VARIABLE CIRCULAR ORIFICE

As the below named inventor, I declare that:

This declaration is directed to the invention titled: " A MIXED-MODE FUEL INJECTOR WITH A MICRO VARIABLE CIRCULAR ORIFICE"

I believe that I am the original and first inventor of the subject matter which is claimed and for which a patent is sought;

I have reviewed and understand the contents of the above-identified application, including the claims, as amended by any amendment specifically referred to above;

I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in 37 CFR 1.56, including for continuation-in-part applications, material information which became available between the filing date of the prior application and the national or PCT International filing date of the continuation-in-part application.

All statements made herein of my knowledge are true, all statements made herein on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001, and may jeopardize the validity of the application or any patent issuing thereon.

FULL NAME OF INVENTOR:

Inventor: Dr. Deyang Hou	Inventor
Signature : /Deyang Hou/	Citizen of : CN

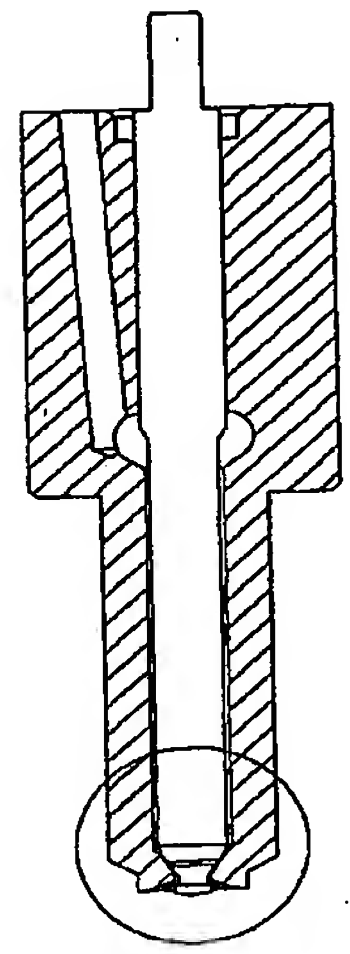


Figure 1

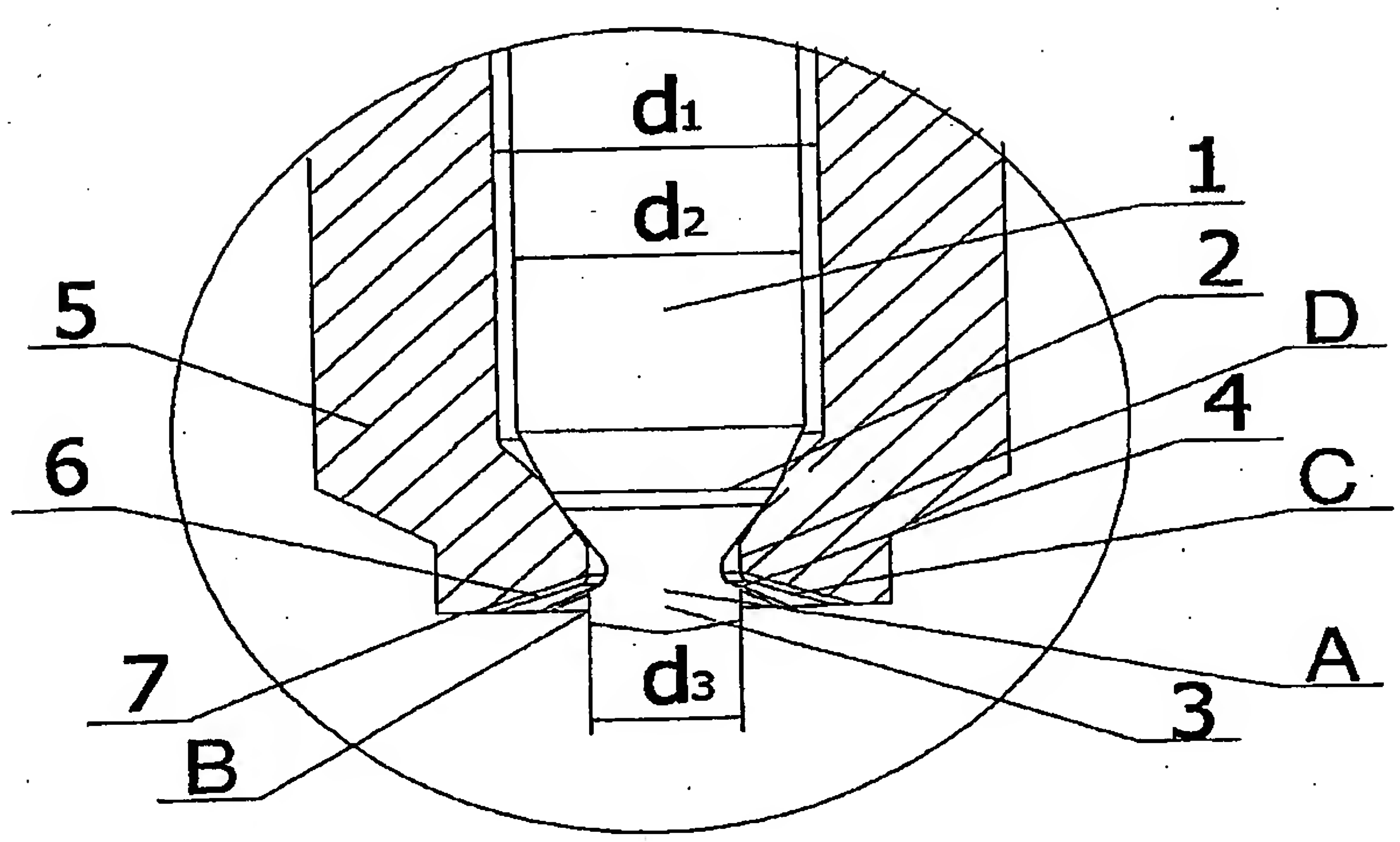
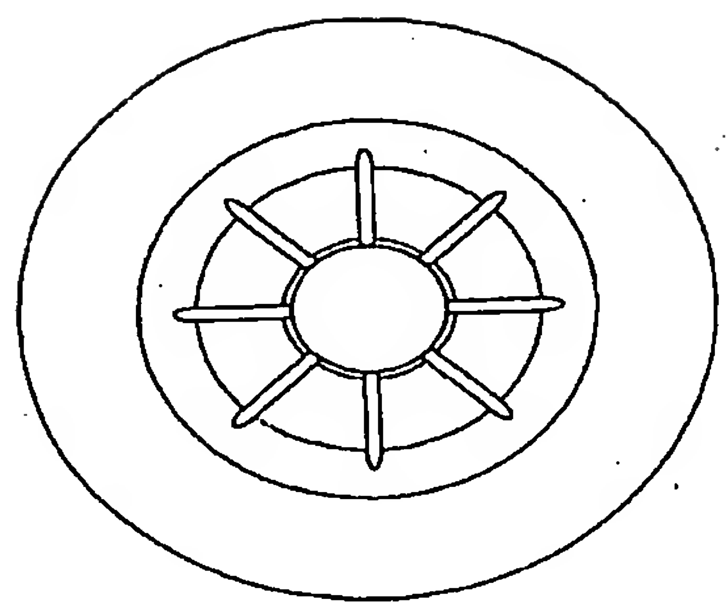


Figure 2



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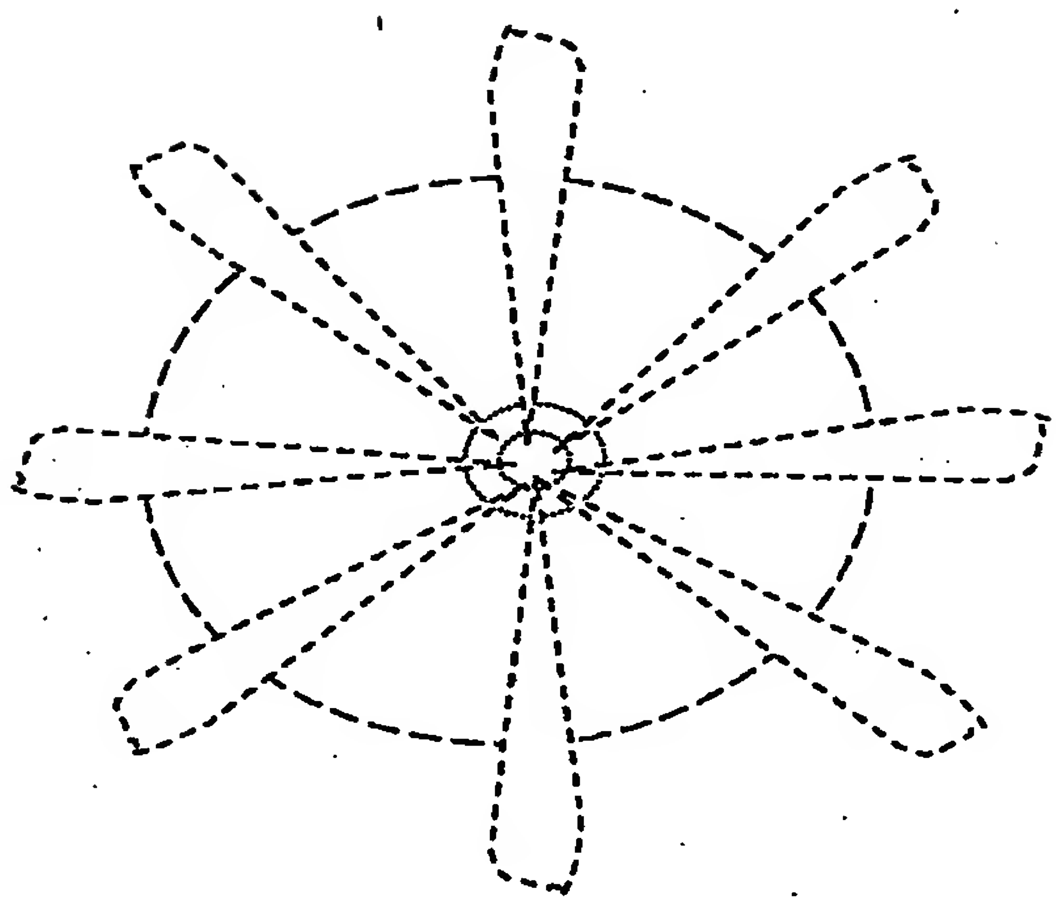

Figure 4

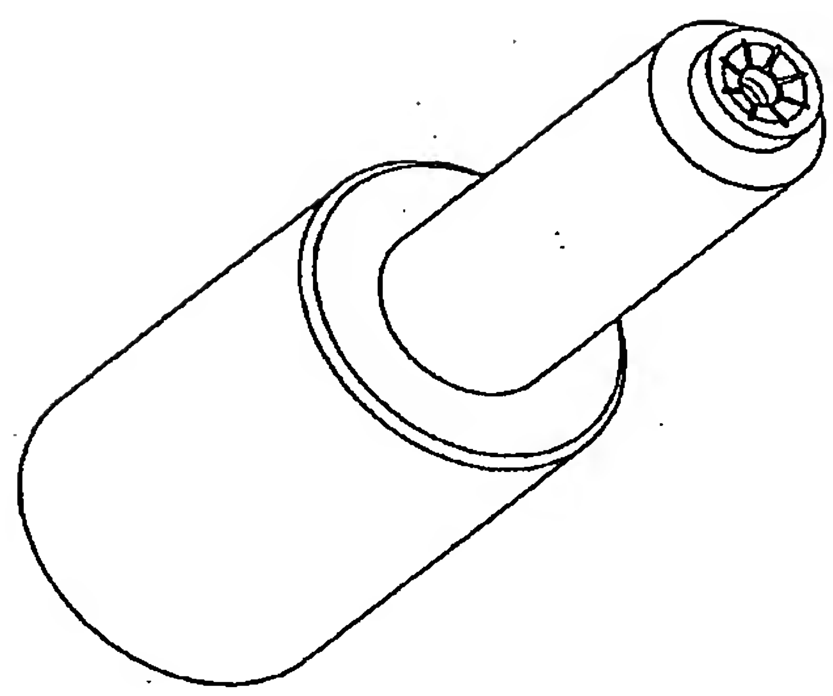

Figure 5